.Physics 2710 – Exam III Name:
December 13, 2017

Please circle the letter corresponding to the *best* answer.

1. An LED emits green photons with wavelength = 500 nm. The LED band gap energy is about
(a) 1.5 eV
(b) 2.5 eV
(c) 3.5 eV
(d) 4.5 eV

Questions 2-3 refer to: An impurity phosphorous (group V) atom in a host silicon (group IV) semiconductor can be thought of as a hydrogen-like atom but with the extra phosphorous electron orbiting in a dielectric medium with a dielectric constant κ. The ground state of these hydrogen-like donor levels is about 0.1 eV below the bottom of the silicon conduction band.

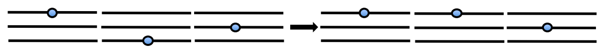
2. κ must be about
(a) 10
(b) 1
(c) 0.1
(d) 0.01

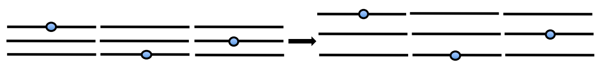
3. If, in the conduction band, there is about one electron donated from the phosphorous atoms for every electron contributed by the silicon atoms, which one of the following is true?
(a) There is about one phosphorous atom for every 10^9 silicon atoms.
(b) There is about one phosphorous atom for every silicon atom.
(c) There is about one silicon atom for every 10^9 phosphorous atoms.
(d) There is about one silicon atom for every mole of phosphorous atoms.

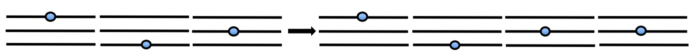
4. The binding energy of a Cooper pair is $3.5k_BT_C$ in a type I superconductor. If the critical temperature for the onset of superconductivity in this material were about 10K the binding energy would be about
(a) 10^{-3} eV
(b) 10^{-1} eV
(c) 1 eV
(d) 10 eV

5. If the number density of helium-4 atoms in a system is sufficiently greater than the corresponding quantum number density the system will be
(a) a degenerate Fermi gas
(b) an electrical superconductor
(c) a superfluid liquid
(d) a classical ideal gas

Questions 6-8 refer to: In the images below the horizontal lines represent single particle energy levels for a small number of identical atoms in a large thermodynamic system. The dots represent the excitation levels of the atoms and the arrows represent thermodynamic processes that change the system's internal energy.

6.  The thermodynamic process is
(a) physical work
(b) chemical work
(c) heat
(d) Maxwellian velocity

7.  The thermodynamic process is
(a) chemical work
(b) physical work
(c) heat
(d) fermion degeneracy

8.  The thermodynamic process is
(a) chemical work
(b) heat
(c) physical work
(d) Bose condensation

Questions 9-11 refer to: The average number of identical, noninteracting particles in a single particle state σ is given by $\bar{N}_\sigma = \dfrac{1}{\exp[(\varepsilon_\sigma - \mu)/k_B T] + A}$.

9. If the particles are fermions, A is
(a) +1
(b) –1
(c) 0
(d) the Fermi energy

10. In the high temperature limit, A is much less than
(a) ε_σ
(b) μ
(c) $k_B T$
(d) $\exp[(\varepsilon_\sigma - \mu)/k_B T]$

11. If the particles are photons what is the value of N_σ at $T = 0$ K?
(a) 1 for energies below the Fermi energy and 0 above it
(b) $N > 0$, the total number of photons at high temperature, all in the ground state
(c) zero for all states
(d) infinite for all states

12. Beryllium, with ground state atomic electronic configuration $1s^2 2s^2$, is a good electrical conductor because
(a) the conduction band is 2s, which can accommodate 2 electrons per atom
(b) the conduction band is 2s, which can accommodate 4 electrons per atom
(c) the conduction band is 2p, which can accommodate 6 electrons per atom
(d) the conduction band is a hybrid combination of 2s+2p, which can accommodate 8 electrons per atom

Questions 13-14 refer to: The number density of electrons in metallic hydrogen (formed under "exotic" conditions) is about 5 times greater than that of the conduction electrons in solid copper. The Fermi energy of the conduction electrons in copper is about 7 eV.

13. The Fermi energy of the electrons in metallic hydrogen is
(a) exactly 0 eV
(b) greater than 7 eV because Fermi energy increases with increasing number density
(c) less than 7 eV because Fermi energy decreases with increasing number density
(d) equal to 7 eV because all electrons are identical

14. The Fermi pressure of the electrons in metallic hydrogen is
(a) 0 atm
(b) about 0.6 atm
(c) about 1 atm
(d) about 10^7 atm

Questions 15-16 refer to: The walls of a box are at temperature $T = 300$ K. The energy density of the blackbody radiation in the box is $6\text{x}10^{-6}$ J/m^3 and the wavelength of the photon corresponding to the maximum in the blackbody energy spectrum is $2\text{x}10^4$ nm.

15. Suppose the temperature is increased to 3000 K. What is the energy density now?
(a) $6\text{x}10^{-2}$ J/m^3
(b) $6\text{x}10^{-5}$ J/m^3
(c) $6\text{x}10^{-6}$ J/m^3
(d) $6\text{x}10^{-10}$ J/m^3

16. Suppose the temperature is increased to 3000 K. What is the wavelength of the photon corresponding to the energy spectrum maximum now?
(a) $2\text{x}10^8$ nm
(b) $2\text{x}10^4$ nm
(c) $2\text{x}10^3$ nm
(d) 2 nm

Questions 17-19 refer to: A macroscopic system consists of identical, noninteracting atoms in an external magnetic field. Each atom has *four* nondegerate magnetic energy states, a ground state and three excited states. The system is in thermal equilibrium with temperature T .

17. The probability an atom will be found in the ground state at $T = 0$ K is
(a) 0
(b) 1/16
(c) 1/4
(d) 1

18. The probability an atom will be found in the ground state at $T = \infty$ K is
(a) 0
(b) 1/16
(c) 1/4
(d) 1

19. If the probability an atom will be found in the ground state is 1/16, the temperature could be
(a) –1000 K
(b) 0 K
(c) 1000 K
(d) ∞ K

20. The circuit to the right executes which voltage conversion table?

A	B	out
+	+	+
+	–	–
–	+	–
–	–	–

(a)

A	B	out
+	+	–
+	–	+
–	+	+
–	–	+

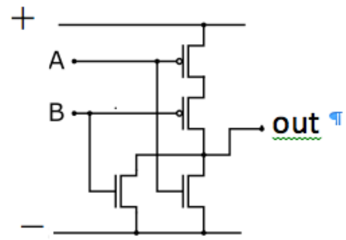
(b)

A	B	out
+	+	+
+	–	+
–	+	+
–	–	–

(c)

A	B	out
+	+	–
+	–	–
–	+	–
–	–	+

(d)



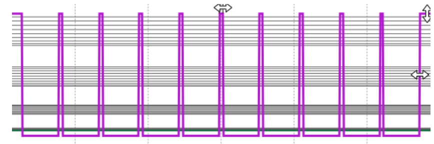
Questions 21-23 refer to: Electrical resistivity of a solid is primarily determined by $\langle v \rangle$–the average speed of a charge carrier between collisions, n_e–the number of free carriers per unit volume, and λ_F–the average distance between successive scatterings. In the questions below, T is temperature.

21. $\langle v \rangle$ is the
(a) Fermi speed, independent of T
(b) average thermal speed of electrons, $\propto \sqrt{T}$
(c) average thermal speed of phonons, $\propto T$
(d) average thermal speed of holes, $\propto 1/T$

22. n_e
(a) is Avogadro's number
(b) always equals 1 electron for every atom
(c) is constant for metals and increases rapidly as temperature increases for semiconductors
(d) always decreases as temperature increases

23. λ_F
(a) decreases as the density of phonons increases with increasing temperature
(b) increases as the density of phonons decreases with increasing temperature
(c) is always the distance between atoms
(d) is the de Broglie wavelength of the electron

Questions 24-25 refer to: The picture to the right represents 10, equally spaced, 1D finite wells with allowed single-particle energy levels. The levels form bands, labeled $n=1$ through 4 in increasing energy.



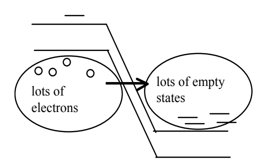
24. Ignoring their charge but including their spin, what is the maximum number of electrons that can occupy the $n=3$ band?
(a) 20
(b) 10
(c) 6
(d) 3

25. Suppose the $n=1$ through 3 bands are fully occupied with electrons and the $n=4$ band is empty. Which *one* of the following corresponds to the "conduction band"? $n=$
(a) 1
(b) 2
(c) 3
(d) 4

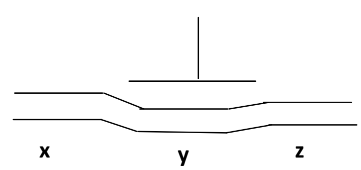
26. The maximum current a superconducting wire can carry is limited by
(a) the critical temperature, T_C
(b) the critical field, B_C
(c) Joule heating
(d) the number of electrons in the wire

27. In the figure to the right a metallic disk hovers over a ceramic plug immersed in liquid nitrogen. This phenomenon is most directly due to the
(a) plug being a pn junction diode
(b) plug being a type II superconductor
(c) disk being a pn junction diode
(d) disk being a type II superconductor

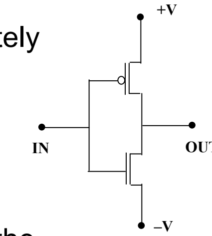
28. The figure to the right depicts valence and conduction bands in a pn junction device. The phenomenon shown is most closely related to
(a) a forward biased diode
(b) a light emitting diode
(c) a NOT gate
(d) tunneling breakdown



29. The figure to the right depicts the band gap in a MOSFET. Which *one* of the following best identifies the doping in regions x, y, and z?
(a) x = p, y = n, z = p
(b) x = n, y = p, z = n
(c) x = p, y = p, z = p
(d) x = n, y = n, z = n

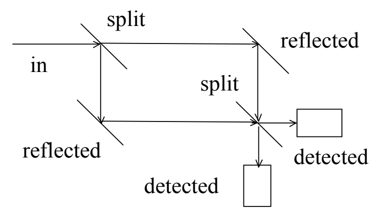


30. In the figure to the right, V = 5 volts and IN = –2 volts. OUT equals approximately
(a) +5 volts
(b) –5 volts
(c) –2 volts
(d) +2 volts



31. In a double slit experiment done with monochromatic (single color) laser light the *wavelength of which is greater than the slit spacing*, there
(a) are no maxima
(b) is exactly one maximum, in the $\theta = 0^\circ$ direction
(c) are two maxima, at $\theta = \pm 10^\circ$
(d) are three maxima, at angles θ that depend on the wavelength

32. When done one photon at a time, the apparatus in the schematic diagram as shown to the right allows one to
(a) determine which path the photon travels over
(b) determine both the photon's particle and wave properties simultaneously
(c) deduce only that a photon has particle properties
(d) deduce only that a photon has wave properties



33. An electron trapped inside a nucleus of diameter equal to 10^{-6} nm would have a kinetic energy on the order of
(a) 10 eV
(b) 1 MeV
(c) 100 MeV
(d) 100 GeV

34. A photon is trapped in a 1D cavity of length L with perfect reflecting ends. The photon wavelength equals $2L/n$, where n is a positive integer. Suppose the color of a photon in the $n = 1$ state is red. How many other different color visible light photon states are allowed in the cavity?
(a) 0
(b) 1
(c) 2
(d) 3

35. A singly ionized carbon-60 molecule, C_{60}^{+}, and a proton, p^{+}, both accelerate from rest through an electric potential difference of 100 V. Which *one* of the following is true? They have equal
(a) momenta
(b) de Broglie wavelengths
(c) masses
(d) kinetic energies

Questions 36-38 refer to: The "sanitized" hydrogen atom problem.

36. The Schrödinger equation is expressed in spherical coordinates because
(a) electrons and protons are spheres
(b) the electron orbits the proton in circles
(c) electrons and protons have spin
(d) the electron-proton potential energy is spherically symmetric

37. The orbital angular momentum of the electron
(a) is conserved because the force of the proton on the electron points toward the proton
(b) has a magnitude of $\frac{1}{2}\hbar$
(c) has a magnitude of $\sqrt{2}\hbar$
(d) is not defined because the electron does not orbit the proton in a circle

38. The electron undergoes an electric dipole transition starting in an $(nlm_l) = (531)$ state. Which *one* of the following is a possible end state?
(a) $(42-1)$
(b) (211)
(c) (310)
(d) (322)

39. The first excited state of Rb (Z = 37) is
(a) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^1$
(b) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 4d^1$
(c) $1s^1 2s^2 3s^2 2p^6 3p^6 4s^2 4p^6 3d^{10} 5s^2$
(d) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 5s^2 4p^5$

40. An electron confined within an infinite cubical well has energy eigenvalues equal to $E_{n_x n_y n_z} = (1\text{ eV})(n_x^2 + n_y^2 + n_z^2)$. The electron undergoes a transition from the first excited state to the ground state. The emitted photon is in which region of the electromagnetic spectrum?
(a) X-ray
(b) ultraviolet
(c) infrared
(d) visible